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The Brazilian energy crisis and a study to support building efficiency legislation

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Abstract

Brazil has gone through an important electricity generation crisis in 2001, but the country does not have as yet a legislation to improve building energy efficiency. The energy efficiency of Brazilian buildings can well be improved, as it was shown during the energy rationing period in 2001. This efficiency increase could usher in gains in quality for indoor environments, as well as lower investments in power generation facilities, including the emission of gases into the atmosphere, flooding arable land for reservoirs, etc. The current work briefly demonstrates the lack of planning that caused the electricity crisis, some results of multi-building studies and simulations of an existing office building of Rio de Janeiro. In this parametric case-study, we have simulated variations of the window–wall ratio (WWR) with different glasses and interior shade, using the natural light, aspects deemed to be of the utmost importance for a future Brazilian building energy efficiency legislation. The need of such legislation has been much increased as a result of the energy generation crisis and its consequences. To take advantage of the problems, in order to improve the quality of the Brazilians buildings, is one of our objectives.

Keywords: Brazilian energy crisis; Building legislation in Brazil; Building envelope

1. Introduction and background on Brazilian energy crisis

The steady rise in living standards of certain segments of the populace in the developing countries is paralleled by power consumption in buildings, measured by square meter, despite the slowdown in growth rates due to more efficient energy end-use technologies. Consequently, heavy investments are required in order to underwrite the expansion in this demand, which keeps pace with the upsurge in new buildings, aiming to avoid serious electricity generation crisis similar to the one we had in 2001.

It was a predicted crisis, since as early as 1995, a group of COPPE (The Post-Graduate School of Engineering of the Federal University of Rio de Janeiro) researchers sent a report to the Brazilian Vice-President warning that the privatization model of the electrical sector would not allow for the generation's expansion, as needed. Hydropower generation needs long-term planning and Brazil has a large electricity generation potential that should not be forgotten. In March 1999, a blackout occurred and it has been wrongly attributed to a lightening, which would have fallen on a minor transformer substation; it was the sign of the nearing crisis. In October 2000, COPPE sent another report to warn the Brazilian President that an energy generation crisis was already outlined. That document proposed some alternatives in order to minimize the problems, such as energy conservation measures, co-generation, and so on. But, only in May 2001, the Government has publicly assumed the crisis and attributed it, once more erroneously, to the scarcity of rain. It was incorrect as the reservoirs were dimensioned considering 5 years dry periods. Even with over-dimensioned reservoirs, it is necessary to invest in new plants each year, as the consumption increases at similar rates to the economy. Until 1994 the reservoirs reached an average of at least 96% of its capacity each year, but since then, the maximum capacity has been declining each year from 1995 to 2000, successively, 89, 77, 88, 83, 70 and 59% [1].

In 1990/2000, the electricity consumption has increased 44.6%, while the installed capacity increased only 28.5% [1]. On the other side, the current marginal power generation and

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transmission costs are much higher than power conservation costs [2], justifying research of tools that encourage power conservation since Brazil has no energy standards to improve the building electricity efficiency.

The problem becomes even more important today in Brazil due to the nation's energy crisis mentioned before, and it is also relevant for the World as a whole due to the issue of climate changes caused by fossil fuel consumption, which prompted the Clean Development Mechanism (CDM) under the Kyoto Protocol, debated again at the Bonn Conference in 2001 and at Johannesburg in 2002, once more.

In Brazil, a very small number of consumers account for a large proportion of power consumption, although per capita figure is low compared to consumption in other countries. In a similar way, some large buildings consume huge amounts of energy in order to provide their residents with First World standards of comfort, albeit in a much less efficient way. Sometimes those buildings consume as much energy as small cities [3]. This unequal use of energy is yet another aspect of a country marked by striking contrasts in the distribution of its wealth.

The cause of the continuous declining of the water reservoirs capacity was the increasing energy consumption. Making good use of natural light in commercial buildings, as we propose, will save energy approximately from 7 a.m. to 7 p.m. each day and besides that will contribute to partially reduce the energy peak as well.

We consider that Brazilian efficiency legislation should firstly focus on large commercial buildings as it has been formerly verified in large commercial buildings with high installed power demands, the potential for power conservation via reduction of lighting power density, for example, may result in interesting retrofits from the financial standpoint [4]. Enhanced energy efficiency for buildings is urged by many authors as an action that produces ample benefits for society [5,6].

In order to increase energy efficiency, studies are required of end-use energy consumption in different types of buildings to support a future Brazilian building efficiency legislation, as outlined by Federal Law 10.295 of 17 October 2001, brought about on the recent energy crisis, but not yet implemented.

In this work, it was used a methodology to assess a current case and then to build-up sensitivity analyses comparing the effects of variations of the main parameters for the existent building. The application of this methodology to a larger and well-distributed sample will help to define the constraints to be included in a future Brazilian regulation.

The legislation's validity becomes more important to the extent that even measures offering a good cost/benefit ratio usually fail to attract builders on a voluntary basis. In Brazil, there is little or no interest in imposed obligations on construction firms in terms of the later energy efficient functioning of their buildings. The player involved with construction does not normally live in the building once it has been completed, meaning that the lowest possible initial investments are sought after, in order to maximize short-term profits, transferring the operating costs to consumers who lack the capacity to assess the quality of what they are purchasing.

2. Potential for upgrading energy efficiency in buildings and case study methodology

Although research into alternative sources of energy for use in buildings dates back to well before the 1973 and 1979 oil crises, it was only after a steady rise in electricity rates that this issue was analyzed exhaustively at the international level. The total amount of primary energy assigned to the Buildings Sector will double worldwide, from 1990 to 2020, should the use of efficient, practical power conservation technologies not be adopted [7]. This growth may be assigned to progress (enhanced living standards); rising GDP; passive population growth; or inefficient equipment, but there seems little doubt that, in absolute terms, the growth of the developing countries will be far lower than that of the developed nations, particularly as the base is smaller. Anyway, the total energy consumption of the developing countries building sector is assessed as three times higher than today [7].

Our purpose here is not to urge the idea of curtailing rising electricity demands as long as this enhances the well being of the populace. However, we feel it is important that this upsurge in demand should be based on efficiency and rational consumption.

Rosenfeld showed that, from 1975 to 1987, the efficiency of commercial buildings inventory in the USA rose at a rate of 2% p.a., achieving an overall improvement for the inventory of 27% over 12 years [6]. There is no data available in Brazil to obtain similar statistics. Even nation-wide energy consumption by each economic sector—which is measured through the Brazilian Energy Balance [8], does not allow any breakdown of the energy consumed exclusively by buildings. So, the effects of regulatory measures are badly assessed, but the technical potential improvement in energy efficiency in Brazil is estimated by Geller et al. [9] to 38%. No data is available to define the amounts that could be saved solely by buildings in Brazil as a whole.

Fig. 1 shows bulk power consumption by square meter and demand by square meter, based on a rare survey of 50 office buildings in six different cities in Brazil [10], obtained through the six cities project, a survey co-ordinated by the PROCEL (Brazilian Agency of Electricity Conservation) [11]. The widely scattered points showing the consumption intensity of these buildings and demand leads to the conclusion that there is ample potential for power conservation, as all of them are office buildings.

2.1. Methodology

First, the results of the simulations based on an existing building (calibration) were checked and later their pa-

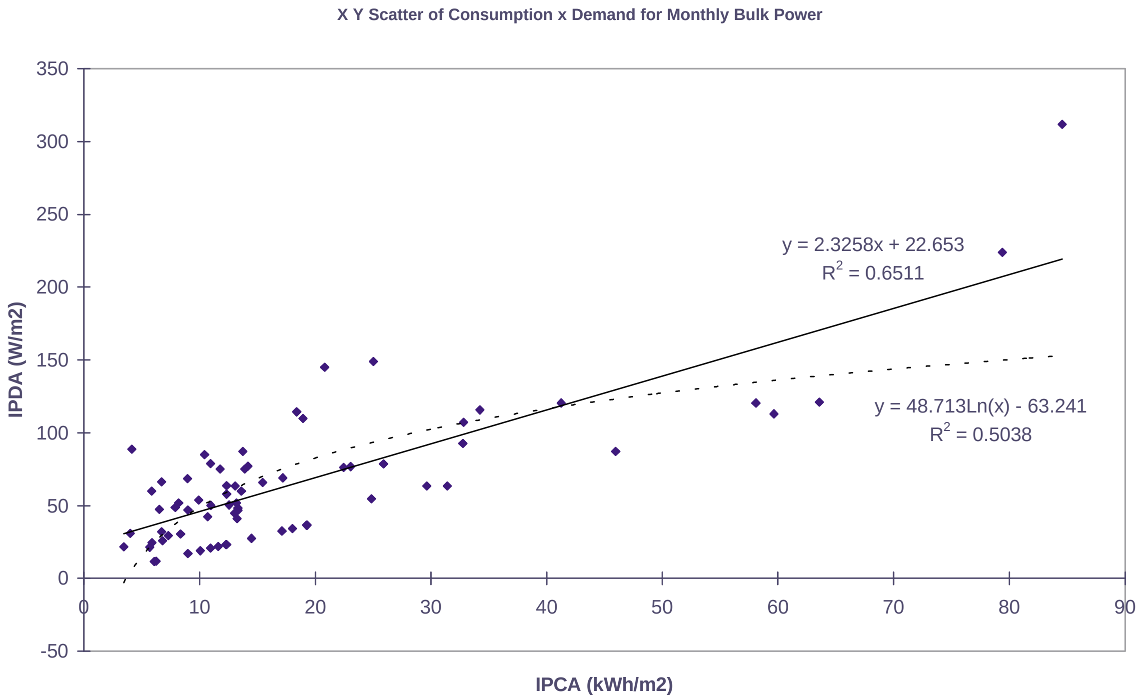

Fig. 1. Power consumption intensity and bulk power demand by area in 50 office buildings in Brazil.

rameters were altered in order to estimate the sensitivity of the major variables. The VisualDOE 2.61 software was used as a support tool for defining the parameters that were analyzed and assessed. We chose Visual-DOE 2.61 since simulation is a credible process that is at a stage of development that takes most variables into account for the building, offering a dynamic overview that takes into account the local climate, construction materials and building uses, while also paving the way for studies of possible alterations.

The office building was selected for this study as it represents a significant segment of the commercial sector. This sector posts the highest economic growth rate and accounts for a large share of the power consumption and GDP of this sector.

The buildings studied initially ran through a calibration phase, where the results of the simulations should be close to the monthly power consumption and bulk power demands metered by the concessionaire, on a monthly basis. This phase was called the base case simulation or calibration stage. The calculation estimated the power consumption and heat load of the building, taking the following items into consideration: (1) constructed volume with internal partitions and outside openings, described in terms of materials, use (office, toilet, lobby, etc.) and dimensions; (2) installed power densities for lighting and equipment; (3) approximate scale of the working hours and usage intensity of the equipment and lighting facilities; and (4) hourly meteorological data for the city of Rio de Janeiro for the year of 1995. Calibration adjusted the timetable and use intensity levels stated by the user for equipment that did not depend on climate, in order to accurately reproduce the data measured by the concessionaire.

The building and its areas were simplified for simulation purposes in order to produce contiguous, homogeneous areas in terms of use, materials and equipment, streamlining the calculations but without violating the project characteristics, which determine the quality of the simulation results.

The purpose of this work did not include flawlessly mirroring the actual metered monthly consumption, but this phase was, nevertheless, carried out in order to bring simulation as close as possible to reality, before moving on to the second stage of the project: a comparison between alternatives based on variations in the architectural design parameters with the highest reliability rating in the results obtained for the consumption under each alternative studied, established on the basis of the calibrated base case.

In contrast to parameter-based studies of hypothetical buildings, we wished to provide better knowledge of existing cases in operation, in order to assess more accurately the real potential for power conservation. Well aware that alterations in building architecture can reduce power consumption, we wished to discover the importance of these reductions compared to other factors in the building energy balance. Is there an ideal proportion of glass in the facades which could serve as a reference figure for architects when designing the outer aspects of these buildings?

The proportion of windows in the facades and the consequent increase in power consumption due to a heavier heat load was studied for the office building. We analyzed the possibility of making better use of natural light for this same building and then we examined the hypothesis of introducing automatic lighting controls in offices, supplementing the natural light in these areas. The uses of low-e glasses and of interior blinds were analyzed.

The building was studied on the basis of a methodology whose objective consisted on checking the effects of altering certain parameters in the architectural designs, which are usually regulated abroad through power conservation regulations. The results of these alterations were shown in sensitivity curves that provide input for a critical analysis of the control values found in the rules for these parameters.

3. Case studies of an office building in the city of Rio De Janeiro

Offices accounted for 32% of the total built area of the city of Rio de Janeiro in 1994 [12]. The case study office building handles administrative tasks with no use of specific equipment other than desktop computers, calculators, photocopying machines, drinking fountains, etc. This building has a roofed area of 1340 m^2, housing the office activities of the Eletrobras Research Center (Fig. 2). This two-storey building is located at the center of a plot of land with windows on two facades on opposite sides. The offices are equipped with air-conditioning facilities.

3.1. Modeling for the administrative building and calibration

The intention here is to analyze the consequences of expanding the window area on the building facades, studying different options. The first option will check the effects on power consumption by simply expanding the window area (what frequently occurs), while the second will increase the window area and consider the possibility of using natural light to supplement artificial light, controlling the supplementary intensity through automatic control, ensuring that the lighting level in the workplace is maintained at 500 lx, in accordance with the Brazilian standard currently in effect [13]. The other two assessments will consider the use of 3 mm low-e glasses and an interior shade made of medium colored blinds which will be open at any time solar gains through the window are less than 95 W/m^2, besides the similar use of the natural light as explained before.

The office windows were resized within the limits of the masonry, varying from 10 to 100% of this area, taking the doors and windows of the infrastructure rooms as constant. We felt that it would be best to work only on the offices where natural lighting would be useful from the standpoint of environmental comfort for users, as well as in areas where this increase would be actually possible, taking into account the existence of beams, pillars and plenums.

The differences between the consumption levels stated by the CEPEL, the ELETROBRAS (the Brazilian Electricity Company) Research Center, and the simulated base-case were greater than expected. The ELETROBRAS Research Center stated that the building had undergone some alterations due to excessive heat, as the air-conditioning system had not worked well in 1995, and some items of equipment had broken down. The employees were allowed to switch the machinery on and off as they wished, according to their own air temperature preferences. In 1996, the glass windows were coated with bronze plastic insulating film as a palliative measure, before replacing some items of equipment, in response to staff complaints. We decided to continue the study, although the calibration reproduced the average consumption with differences of up to 37% in June, but averaging out at 0%, due to outside factors that adversely affected the simulation and could not be reproduced due to a lack of information, but nevertheless did not invalidate the

Fig. 2. Outside view of the office building with its unshaded glass.

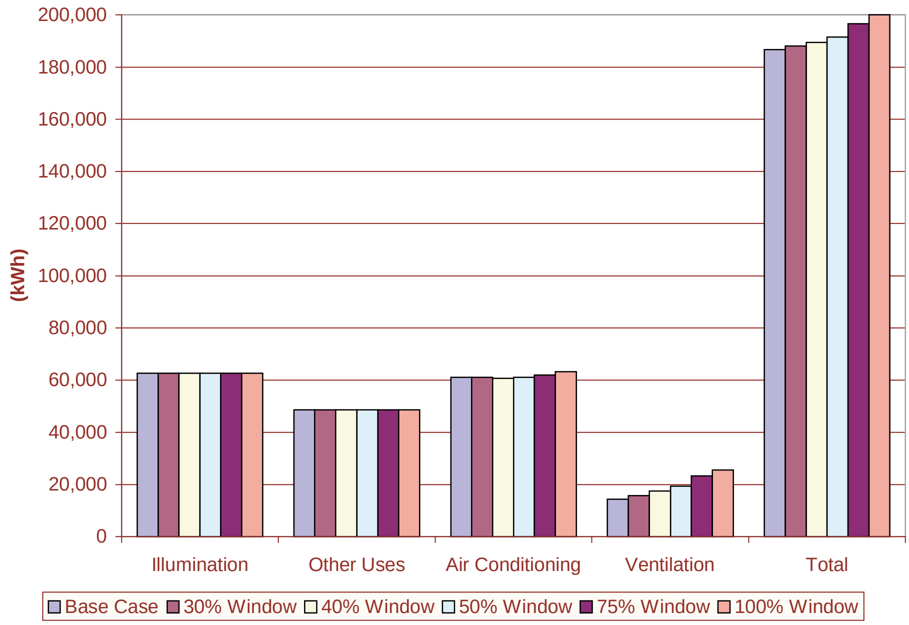

Fig. 3. Effects of altering the window proportions on annual energy consumption, not making good use of natural light.

study. The annual actual consumption is 148 kW h/m^2 and the simulated consumption is 139 kW h/m^2.

The results of power consumption by end-use are similar to those seen in office buildings found in the literature [3,14,15]. Air-conditioning and fans account for 41%, while lighting reaches 33%. Other energy end-uses include calculators, computers, drinking fountains, photocopying machines, printers, etc., accounting for 26% of the total power consumption.

3.2. The problem of the window wall area proportion

3.2.1. Assessing the variation in the proportion of windows in the facades, without using natural light

The actual building's window area covers 140 m^2, representing 22% of the total area that could be opened up to the outside through frames. We varied this area in order to estimate the power consumption by end-use for each alternative window area proportion, as shown in Fig. 3, where lighting and other uses remained constant, as expected, while air-conditioning and fans rose steadily as the window area increases.

The ratio between electricity consumption and the window area proportion is directly related to the expansion in the alternatives, as shown in Fig. 3. This is due basically to the heat load's increase caused by expanding the glass area. The linear ratio between consumption by area unit and the window area proportion reached a r^2 of 0.99. The high level of direct dependence between power consumption and the window area proportion was confirmed. The monthly electricity consumption figures given in Fig. 4 shows the seasonal climatic influence.

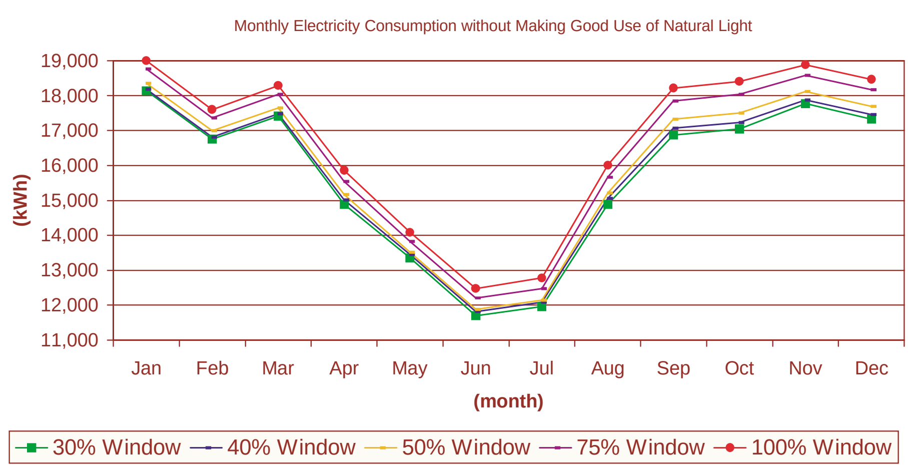

Fig. 4. Monthly electricity consumption without natural light, base-case.

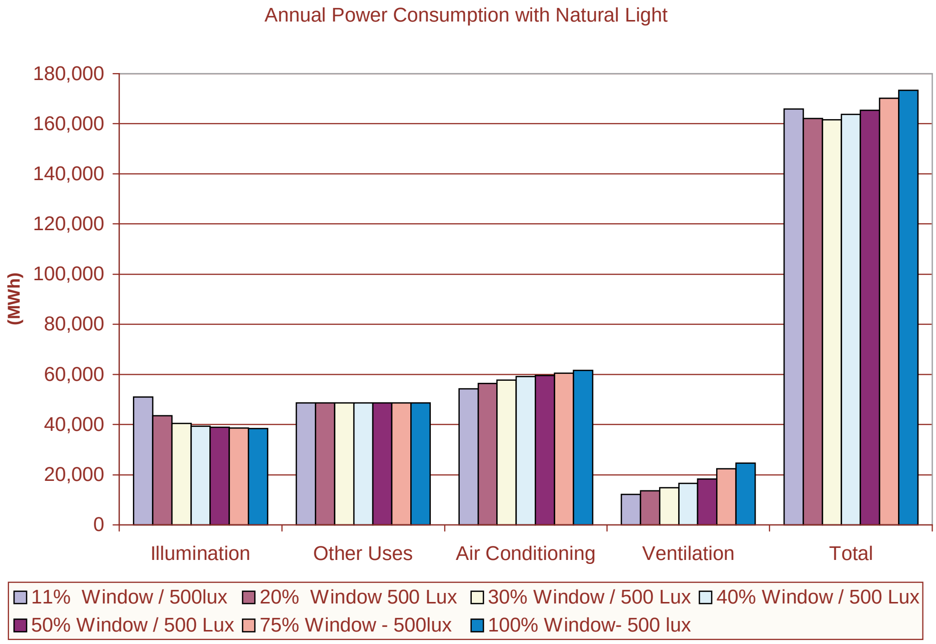

Fig. 5. Effects of altering the window proportions, making good use of natural light.

3.2.2. Assessment of the variation in proportion of windows in the facades, making good use of natural light

This study becomes more interesting when good use is made of natural light, because as the addition of natural light reduces electricity consumption for the lighting end-use, the increase in the heat load for the building, conducted by thin glass walls and direct radiation through them, results in an increase in electricity consumption by the air-conditioning system. We simulated also the use of low-e glasses and internal blinds.

The Fig. 5 shows the effects on annual power consumption by end-use and alterations in the proportion of the windows. This first approach indicates the relationship between the heat gains and the profitable use of the natural light, and it also states that there is an optimum value for the WWR of this building.

The sensitivity analysis clearly indicates an optimum window proportion in relation to the facade area from the energy standpoint. This proportion hovers around 30%, when electricity consumption reaches its lowest level. Reducing

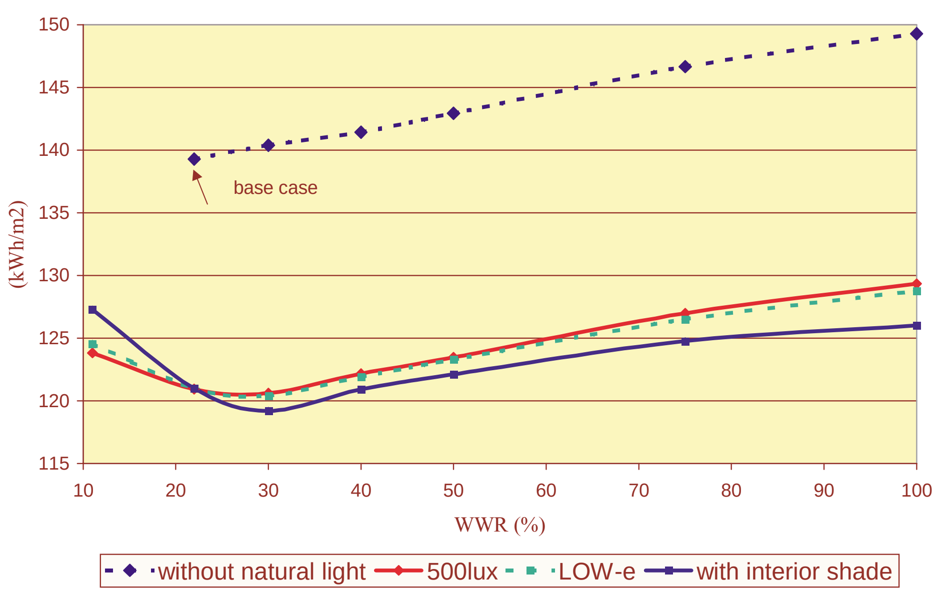

Fig. 6. Electricity consumption sensitivity analysis by area, varying the window area proportion without natural light and using natural light (500 lx) with common glass and low-e glass/interior shade.

the window size beyond this point reduces the useable natural light more than the heat load and results in an increase in total energy consumption, meaning that a window sized <30% is not recommended. When covering more than 30% of the facade, the windows increase the heat load more than the useable natural light, requiring more power to offset this added heat load than the consumption avoided through automated lighting facilities. The simulations of the low-e glasses of 3 mm (however, not usual in Brazil) have shown that the energy consumption was similar to the latter simulation, but it is a better solution for larger WWR. In the following simulations, we have tested windows with a medium colored Venetian blind that is closed when solar gain exceeds 95 W/m^2. It is by far the best solution, as it is shown in Fig. 6.

4. Conclusions

In this work, we have studied an office building typology and we have examined alterations on WWR and other variables, such as the use of natural light, different glasses (transparent and low-e) and interior shades. Many other aspects of building energy use need detailed study and results should be considered when developing an effective building energy efficiency standard. The unique aspect of the WWR analysis was selected to be studied in this article as it is that some no-cost or very low cost approaches that can save significant electricity. Other very low cost building aspects will be the focus of further works.

The respect to the ideal proportion of the windows in facades together with the use of natural light in the office building could reduce its energy consumption by up to 13.4% and even more with the use of low-e glasses (13.6%) or with interior blinds (14.4%). The conclusion is reached that optimized proportion of the windows alone offers significant potential for power savings and the use of interior blinds may well improve the savings considerably.

We hope those results will give an initial support to a Brazilian legislation and the allocated funds to energy conservation research will be used in the same way as several other countries have already done before, in an effective and specific legislation for energy efficiency legislation for the construction industry that should take into consideration the climates, materials as well as the unequal distribution of incomes and electricity consumption among the social layers throughout Brazil.

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